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(54) **Spectrophotometer with optical filters and electrostatic shutters**

Spektrophotometer mit optischen Filtern und elektrostatischen Verschlüssen

Spectrophotomètre utilisant des filtres optiques et des obturateurs électrostatiques

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(73) Proprietor: **C.R.F. Società Consortile per Azioni
10043 Orbassano (TO) (IT)**

(72) Inventor: **Pizzi, Marco
10100 Torino (IT)**

(74) Representative: **Notaro, Giancarlo
c/o Buzzi, Notaro & Antonielli d'Oulx
Via Maria Vittoria 18
10123 Torino (IT)**

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Description

[0001] The present invention relates to the spectrophotometers.

[0002] The document EP 1 243 902 A1 in the name of the present applicant illustrates a spectrophotometer comprising:

- a light source;
- separator means, for separating the light beam coming from the source into various components corresponding to different wavelengths;
- selector means, for selecting one or more of the components of the light beam that are generated by said separator means; and
- sensor means for receiving the component selected by said selector means and for emitting at output electrical signals indicating the wavelength of the radiation received.

[0003] The spectrophotometer known from said document uses a separator element of any known type (for example a prism or a grating) to separate the light beam at output from the source into its components corresponding to the different wavelengths. The selection of one or more of the components of the light beam that are separated by means of said separator element is performed by means of an aligned set or a matrix array of electrostatic micro-shutters. The radiation selected by means of the electrostatic micro-shutters is made to converge on sensor means formed by a single sensor, for example a single photodiode, so as to avoid the high costs and complications of known solutions, which envisage sensor means formed by an array of photodiodes.

[0004] The purpose of the present invention is to propose a solution alternative to the known solution described above, which will be characterized by constructional simplicity, low production costs, and extremely small dimensions, with a view to favouring use thereof, for example, in applications such as the detection of the composition of the exhaust gases of the engine of a motor vehicle by means of a spectrophotometer provided on board said vehicle.

[0005] A spectrophotometer according to the preamble of claim 1 is known from US-B1-6 191 860.

[0006] A spectrophotometer according to the present invention is defined in claim 1.

[0007] According to a further preferred characteristic of the invention, the aforesaid selector means comprise a plurality of micro-shutters that can be actuated independently of one another.

[0008] Each of the aforesaid micro-filters is associated to a respective micro-shutter so as to obtain an extremely compact assembly, capable of selecting the wavelengths of interest without any need for additional elements for splitting the beam into its components, as in the case of the known solution. In one example of embodiment, the aforesaid optical micro-filters are of the interference type.

[0009] There are provided electronic-control means for receiving and processing the signals at output from the sensor means and for controlling the electric power supply to the individual electrostatic micro-shutters for the purpose of selecting the wavelengths that are each time of interest.

[0010] According to a further important characteristic of the invention, there are provided means for conveying the radiation leaving the optical filters selected by means of the micro-shutters in the direction of the sensor means. Said guide means are formed, in a first example of embodiment, by a series of optical fibres that extends from the outputs of the micro-filters up to the aforesaid sensor means. There are of course provided coupling elements, of any known type, between the ends of the optical fibres and the optical micro-filters, on one side, and between the ends of the optical fibres and the sensor means, on the other.

[0011] In an alternative embodiment, the aforesaid means for guiding radiation from the filters selected to the sensor means are formed by a light-guide element that exploits phenomena of total inner reflection (T.I.R.). The same sublayer could function as light guide if a dielectric layer with appropriate index of refraction is deposited on the face opposite to that of the micro-shutters.

[0012] A further subject the invention is a method for controlling the spectrophotometer described above. According to the invention, between the selection of two different micro-filters performed by means of the micro-shutters there is introduced a dark phase, in which all the micro-shutters are closed. Alternatively, it is possible to open and close one and the same micro-shutter a number of times before passing on to the next one. In this way, it is not necessary to use an additional chopper, as required in the known solutions that make use of certain types of sensors.

[0013] Further characteristics and advantages of the invention will emerge from the ensuing description with reference to the annexed drawings, which are provided purely by way of non-limiting example, and in which:

- Figure 1 is a schematic view of a spectrophotometer according to the known art illustrated in EP 1 243 902 A1;
- Figure 2 is a partial cross-sectional view of a detail of an embodiment of the known spectrophotometer;
- Figure 3 illustrates a known variant of the spectrophotometer of Figure 2;
- Figure 4 is a schematic cross-sectional view of a first embodiment of the spectrophotometer according to the invention; and
- Figure 5 is a schematic cross-sectional view of a second embodiment of the spectrophotometer according to the invention.

[0014] With reference to Figure 1, the reference number 1 designates, as a whole, a spectrophotometer of the type illustrated in the document EP 1 243 902 A1.

The spectrophotometer 1 comprises a light source 2, and a separator element 3 of any known type, designed to separate the light beam leaving the source 2 into its components corresponding to the different wavelengths. Set downstream of the separator device 3 is an electrostatic micro-shutter device 4 that is illustrated in detail in what follows. Said device is designed for selecting a single desired wavelength in the beam emitted by the separator element 3. The radiation emitted is then made to converge by an optical element 5 on top of a single sensor 6, of any known type, for example a pyro-electric sensor or a photodiode, designed to emit at output an electrical signal that is a function of the light energy received.

[0015] Figure 2 illustrates an embodiment of the electrostatic micro-shutter device 4. According to said embodiment, there is provided an aligned set of mobile-petal micro-shutters 7, arranged on top of a substrate 8, for example formed by a transparent material, such as germanium, silicon, quartz or glass, having a thickness of a few millimetres or centimetres. Applied on top of the substrate 8 is a film 9 made of transparent conductive material, for example indium tin oxide (ITO), which has a thickness of a few tens or hundreds of nanometres and is obtained, for example, by means of vapour deposition, spin coating, silk-screen printing, or dipping. The film 9 constitutes a first electrode of the device, which is common to all the micro-shutters. It is coated with a layer of transparent insulating material 10, having a thickness, for example, of the order of a few micrometres, obtained with techniques similar to the ones adopted for the film 9. The layer 10 can be formed by a dielectric material, preferably tantalum oxide (Ta_2O_5) or by a ferro-electric material, for example lead zircono-titanate (PZT) or the like (e.g., lanthanates). Set on top of the dielectric layer 10, in a plane orthogonal to the direction of the light beam, is an aligned series or a matrix array of mobile petals 11, each formed, for example, by a dielectric film, on which a metallized layer 12 functioning as second electrode is applied. Each petal 11 has one end secured to the layer 10 and, in its undeformed condition, assumes a curled-up configuration, in such a way as to enable passage of light through the respective portion of the substrate 8. The device comprises electric power supply means for applying a potential difference between the first electrode 9 and the second electrode 12 of a petal 11 selected. Following upon application of the voltage, the petal distends over the layer 10 adhering thereto by electrostatic effect, and consequently obstructing the passage of light through the respective portion of substrate. By controlling the electric power supply to the electrostatic micro-shutters 7 it is thus possible to select a single desired wavelength of the radiation leaving the separator element 3.

[0016] Figure 3 illustrates a variant in which the electrode 9 can be made of a low-cost non-transparent metal material, in which case there is provided a micro-window 13 in a position corresponding to each petal 11. Also the substrate 8 may be made of non-transparent material and have an opening 14 in a position corresponding to

each petal. Finally, also the insulating layer 10 preferably has a hole 15 facing the openings 13, 14.

[0017] With reference now to Figure 4, a first embodiment of the spectrophotometer according to the invention will be described. An important difference of the spectrophotometer according to the invention as compared to the known spectrophotometer illustrated in Figures 1-3, lies in the fact that the separation of the light beam leaving the source 2 into its components of different wavelength is obtained using a plurality of optical micro-filters, each designed to allow just one given wavelength of the light radiation to pass. In the case of Figure 4, the optical filters, designated by the reference number 20, are arranged, according to an aligned arrangement or a matrix array, within the same substrate 8 of the set of electrostatic micro-shutters 7. The structure of the micro-shutters 7 may be altogether identical to the one illustrated in Figure 2, and hence, in Figures 4, 5, parts corresponding to those illustrated in Figures 1-3 are designated by the same reference numbers. The micro-shutters 7 have an arrangement identical to that of the micro-filters 20 (aligned set or matrix array), in a plane orthogonal to the direction of the light beam L coming from the source (not visible in Figures 4 and 5). In the embodiment illustrated, the substrate 8 may be made of a non-transparent material, and the same applies to the layer of the electrode 9 and the insulating layer 10, in so far as the latter have the openings 13, 15 and define micro-windows in positions corresponding to each micro-filter 20. As has already been said, each micro-filter 20 is set within the substrate 8, i.e., it is mounted in a position corresponding to a through cavity made in the substrate, thus creating an extremely simple and compact structure. The outputs of the optical micro-filters 20 are connected by means of coupling elements 21, of any known type, to respective ends of optical fibres 22, the opposite ends of which converge in an optical-coupling element 23, which is also of any known type, for coupling with sensor means 24, of any known type, preferably formed by a single pyro-electric sensor or by a single photodiode, the output signals of which are sent to a processing and control unit 25, which also sends signals 26 for controlling the electric power supply to the various micro-shutters 7, for enabling selection of the desired wavelengths, and signals 27 to display means (not illustrated) for displaying the results of the processing operations.

[0018] In use, the control unit 25 carries out activation of the micro-shutters 7 for the purpose of selecting each time the desired wavelengths. Only the micro-shutter 7 that each time is in the open condition enables passage of light L, which undergoes filtering by the corresponding micro-filter 20. The corresponding optical fibre 22 hence conducts to the sensor 24 only the radiation having the desired wavelength. The signals at output from the sensor means 24 are sent to the control unit 25, which displays the results obtained.

[0019] As has already been mentioned above, preferably, between the opening of two different micro-shutters

7 there is left a dark phase, in which all the shutters are closed. Alternatively, it is possible to open and close one the same micro-shutter 7 a number of times before passing to the next one. In this way, it is not necessary to use an additional chopper, as required by some types of known sensors.

[0020] Figure 5 illustrates an alternative embodiment, which differs from that of Figure 4 only in the way in which the radiation leaving the micro-filters 20 are guided to the sensor 24. In this case, the optical-fibre system 22 of Figure 4 is replaced by a single element 28 constituting a light guide, of type in itself known, designed to convey the light exploiting phenomena of total inner reflection (T.I.R.). The sensor 24 is, in this case, set at one end of the optical guide 28, with consequent further reduction of the dimensions of the overall device. For the purposes of a correct exploitation of the phenomena of total inner reflection, it is preferable for the light beam L directed onto the array of micro-shutters to have an inclination with respect to the direction orthogonal to the plane of the array of micro-shutters, as illustrated in Figure 5.

[0021] As emerges clearly from the foregoing description, the fundamental advantage of the present invention as compared to the known solution described above lies in the fact that the need for a prism element upstream of the array of micro-shutters for splitting the beam into its components is eliminated completely, the selection made by the micro-shutters being obtained already on specific wavelengths of the radiation, thanks to the use of the micro-filters, with the consequence of a overall structure of the spectrophotometer that is more simple and more compact.

[0022] Of course, without prejudice to the principle of the invention, the details of construction and the embodiments may vary widely with respect to what has been described and illustrated herein purely by way of example, without thereby departing from the scope of the present invention.

Claims

1. A spectrophotometer, comprising:

- a light source (2);
- separator means (20) for separating the light beam coming from the source (2) into different components corresponding to different wavelengths;
- selector means (7) for selecting one or more of the components of the light beam that are generated by said separator means (20);
- sensor means (24) for receiving the component selected by said selector means (7) and for emitting at output electrical signals indicating the wavelength of the radiation received;

wherein:

- said separator means are formed only by a plurality of optical filters (20), which can select different wavelengths, and

- said selector means comprise a plurality of micro-shutters (7), that can be actuated independently of one another, to which the aforesaid optical filters (20) are respectively associated,

so that the light beam is not split into the different wavelengths upstream of the selector means, said spectrophotometer being **characterized in that:**

- said micro-shutters (7) are electrostatic micro-shutters,

- said electrostatic micro-shutters (7) comprise: a common substrate (8); an electrically conductive layer (9) functioning as common electrode, applied on one face of the substrate (8); an insulating layer (10) set on top of the common electrode (9); and a plurality of separate thin-film electrodes (11), each having one end anchored to the insulating layer (10) and the remaining part mobile between a condition of rest, in which the electrode (11) leaves free the passage of the light (L) through the substrate (8) and an activated condition where it is adherent to the substrate, in which the passage of the light is obstructed,

- said optical filters (20) are arranged within the aforesaid substrate (8),

- said sensor means consists of a single sensor formed, for example, by a pyro-electric sensor or a photodiode,

- and **in that** there are provided means for guiding the radiation separated by said micro-filters (20) towards said single sensor (24).

2. The spectrophotometer according to Claim 1, **characterized in that** said guide means are formed by a series of optical-fibres (22), which extends from the outputs of the optical-filters (20) up to the aforesaid sensor means (23).

3. The spectrophotometer according to Claim 2, **characterized in that** at the ends of each optical fibre (22) there are provided optical-coupling means (21, 23), for coupling, respectively, with an optical-filter (20) and with the aforesaid sensor means (24).

4. The spectrophotometer according to Claim 1, **characterized in that** said guide means are formed by a light-guide element (28), which exploits the phenomenon of total inner reflection (T.I.R.).

5. The spectrophotometer according to Claim 4, **characterized in that** said light guide means (28) is in the form of a plate set parallel to and adjacent to the

arrangement of the aforesaid optical filters (20), with the sensor means (24) arranged at one end of said plate (28).

6. The spectrophotometer according to each of the previous Claims, **characterized in that** the optical-filters (20) are of an interference type. 5
7. The spectrophotometer according to Claim 1, **characterized in that** it envisages an electronic control unit (25) for receiving and processing the signals at output from said sensor means (24), for emitting at output signals (27) to means for displaying the results of the processing operation, and control signals (26) for controlling electrical supply to the electrostatic micro-shutters (7). 10 15

Patentansprüche

1. Spektrophotometer, umfassend:

- eine Lichtquelle (2);
- Separatormittel (20), um das von der Quelle (2) kommende Lichtbündel in unterschiedliche Komponenten zu trennen, die unterschiedlichen Wellenlängen entsprechen;
- Selektormittel (7), um eine oder mehrere der Komponenten des Lichtbündels auszuwählen, die durch das genannte Separatormittel (20) erzeugt sind;
- Sensormittel (24), um die durch das genannte Selektormittel (7) ausgewählte Komponente zu erhalten und um am Ausgang elektrische Signale auszusenden, die die Wellenlänge der erhaltenen Strahlung anzeigen;

worin:

- die genannten Separatormittel lediglich durch eine Mehrzahl optischer Filter (20) gebildet sind, welche unterschiedliche Wellenlängen auswählen können, und
- die genannten Selektormittel eine Mehrzahl von Mikroverschlüssen (7), die unabhängig voneinander betätigt werden können, umfassen, mit denen die vorgenannten optischen Filter (20) jeweils verbunden sind,

so dass das Lichtbündel in die unterschiedlichen Wellenlängen nicht stromaufwärts der Selektormittel aufgeteilt wird, 50

- wobei genanntes Spektrophotometer **dadurch gekennzeichnet ist, dass:**
- die genannten Mikroverschlüsse (7) elektrostatische Mikroverschlüsse sind,
- die genannten elektrostatischen Mikrover-

schlüsse (7) umfassen: ein gemeinsames Substrat (8); eine elektrisch leitende Schicht (9), die als gemeinsame Elektrode fungiert, aufgebracht auf eine Seite des Substrates (8); eine isolierende Schicht (10), die auf der Oberseite der gemeinsamen Elektrode (9) angeordnet ist; und eine Mehrzahl gesonderter Dünnschichtelektroden (11), die jede mit einem Ende an der isolierenden Schicht (10) verankert sind und deren anderer Teil zwischen einem Ruhezustand, in dem die Elektrode (11) den Durchtritt des Lichtes (L) durch das Substrat (8) frei läßt, und einem aktivierten Zustand bewegbar ist, wo sie am Substrat anhaftet, wobei der Durchtritt des Lichtes verhindert ist;

- die genannten optischen Filter (20) innerhalb des vorgenannten Substrates (8) angeordnet sind,

- das genannte Sensormittel aus einem einzelnen Sensor besteht, der beispielsweise aus einem pyro-elektrischen Sensor oder einer Photodiode besteht,

- und dass Mittel vorgesehen sind, um die durch die genannten Mikrofilter (20) aufgeteilte Strahlung zu dem genannten einzelnen Sensor (24) hin zu leiten.

2. Spektrophotometer nach Anspruch 1, **dadurch gekennzeichnet, dass** die genannten Leitermittel durch eine Reihe optischer Fasern (22) gebildet sind, die sich von den Ausgängen der optischen Filter (20) bis zum vorgenannten Sensormittel (24) erstreckt.

3. Spektrophotometer nach Anspruch 2, **dadurch gekennzeichnet, dass** an den Enden sämtlicher optischer Fasern (22) Optokopplermittel (21, 23) vorgesehen sind, um mit einem optischen Filter (20) bzw. mit dem vorgenannten Sensormittel (24) zu koppeln.

4. Spektrophotometer nach Anspruch 1, **dadurch gekennzeichnet, dass** die genannten Leitermittel durch ein Lichtleitelement (28) gebildet sind, welches das Phänomen der inneren Totalreflexion (T. I. R.) ausnutzt.

5. Spektrophotometer nach Anspruch 4, **dadurch gekennzeichnet, dass** das genannte Lichtleitelement (28) die Form einer Platte hat, die parallel zu der und angrenzend an die Anordnung der vorgenannten optischen Filter (20) angeordnet ist, wobei das Sensormittel (24) an einem Ende der genannten Platte (28) angeordnet ist.

6. Spektrophotometer nach jedem der vorausgehenden Ansprüche, **dadurch gekennzeichnet, dass** die optischen Filter (20) vom Interferenztyp sind.

7. Spektrophotometer nach Anspruch 1, **dadurch gekennzeichnet, dass** es eine elektronische Steuereinheit (25) ins Auge faßt, um die Signale am Ausgang des genannten Sensormittels (24) zu empfangen und zu verarbeiten, um am Ausgang Signale (27) für eine Sichtanzeige der Ergebnisse der Signalverarbeitung sowie Steuersignale (26) für die Steuerung der elektrischen Versorgung für die elektrostatischen Mikroverschlüsse (7) abzugeben.

Revendications

1. Spectrophotomètre, comprenant :

- une source de lumière (2) ;
- des moyens séparateurs (20) pour séparer le faisceau lumineux venant de la source (2) en différentes composantes correspondant à des longueurs d'onde différentes ;
- des moyens sélecteurs (7) pour sélectionner une ou plusieurs des composantes du faisceau lumineux qui sont générées par lesdits moyens séparateurs (20) ;
- des moyens capteurs (24) pour recevoir la composante sélectionnée par lesdits moyens sélecteurs (7) et pour émettre en sortie des signaux électriques indiquant la longueur d'onde du rayonnement reçu ;

dans lequel

- lesdits moyens séparateurs sont formés seulement par une pluralité de filtres optiques (20), qui peuvent sélectionner différentes longueurs d'onde, et

lesdits moyens sélecteurs comprennent une pluralité de micro-obturbateurs (7) qui peuvent être actionnés indépendamment les uns des autres, auxquels sont respectivement associés les filtres optiques (20) susmentionnés, de sorte que le faisceau lumineux n'est pas divisé dans les différentes longueurs d'onde en amont des moyens sélecteurs, ledit spectrophotomètre étant **caractérisé en ce que**

- lesdits micro-obturbateurs (7) sont des micro-obturbateurs électrostatiques,
- lesdits micro-obturbateurs électrostatiques comprennent : un substrat commun (8) ; une couche conductrice électrique (9) servant d'électrode commune, appliquée sur une face du substrat (8) ; une couche isolante (10) placée par-dessus l'électrode commune (9) ; et une pluralité d'électrodes à film mince séparées (11) ayant chacune une extrémité ancrée à la couche

isolante (10) et la partie restante mobile entre un état de repos, dans lequel l'électrode (11) laisse libre le passage de la lumière (L) à travers le substrat (8) et un état activé dans lequel elle adhère au substrat, dans lequel le passage de la lumière est obstrué,
 - lesdits filtres optiques (20) sont agencés dans le substrat (8) susmentionné,
 - lesdits moyens capteurs consistent en un unique capteur formé, par exemple, d'un capteur pyroélectrique ou d'une diode photoélectrique,
 - et **en ce qu'il** est prévu des moyens pour guider le rayonnement séparé par lesdits micro-filtres (20) en direction dudit capteur unique (24).

2. Spectrophotomètre selon la revendication 1, **caractérisé en ce que** lesdits moyens de guidage sont formés par une série de fibres optiques (22) qui s'étendent depuis les sorties des filtres optiques (20) jusqu'aux moyens capteurs (23) susmentionnés.

3. Spectrophotomètre selon la revendication 2, **caractérisé en ce qu'**aux extrémités de chaque fibre optique (22) sont prévus des moyens de couplage optique (21, 23) pour un couplage, respectivement, avec un filtre optique (20) et avec les moyens capteurs (24) susmentionnés.

4. Spectrophotomètre selon la revendication 1, **caractérisé en ce que** lesdits moyens de guidage sont formés par un élément guide de lumière (28) qui exploite le phénomène de réflexion interne totale (TIR).

5. Spectrophotomètre selon la revendication 4, **caractérisé en ce que** lesdits moyens de guidage de lumière (28) prennent la forme d'un jeu de plaques parallèle à et proche de l'agencement des filtres optiques (20) susmentionnés, avec les moyens capteurs (24) placés à une extrémité de ladite plaque (28).

6. Spectrophotomètre selon chacune des revendications précédentes, **caractérisé en ce que** les filtres optiques (20) sont d'un type à interférence.

7. Spectrophotomètre selon la revendication 1, **caractérisé en ce qu'il** comprend une unité de commande électronique (25) pour recevoir et traiter les signaux à la sortie desdits moyens capteurs (24), pour émettre en sortie des signaux (27) à des moyens pour afficher les résultats de l'opération de traitement, et des signaux de commande (26) pour contrôler l'alimentation électrique des micro-obturbateurs électrostatiques (7).

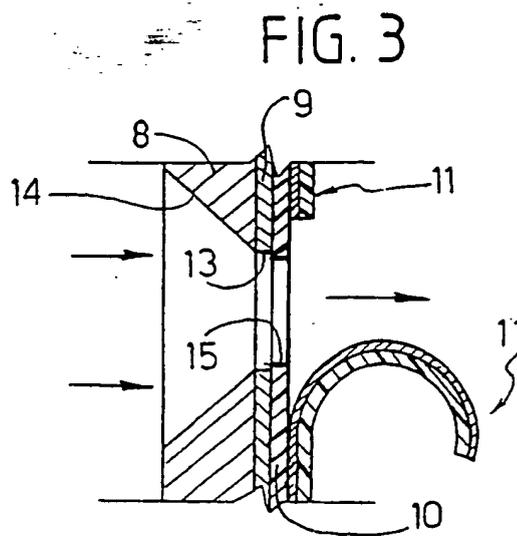
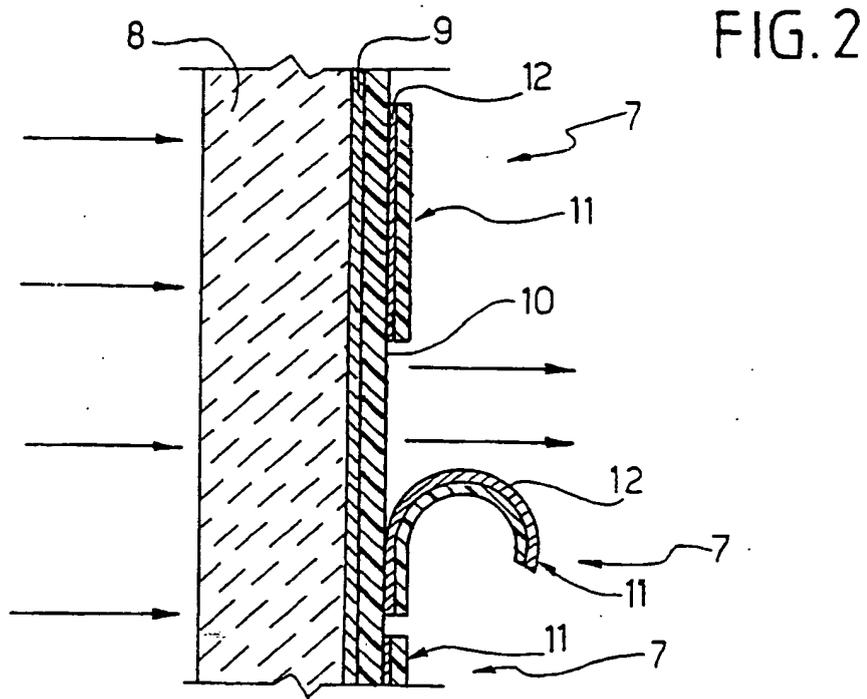
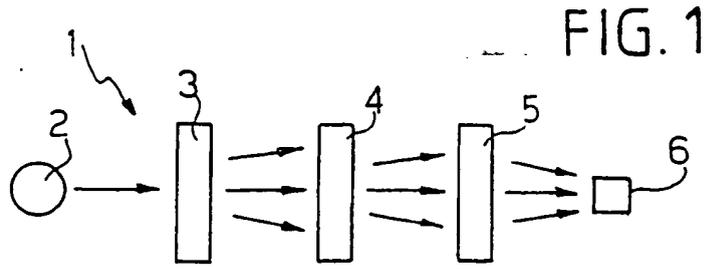


FIG. 4

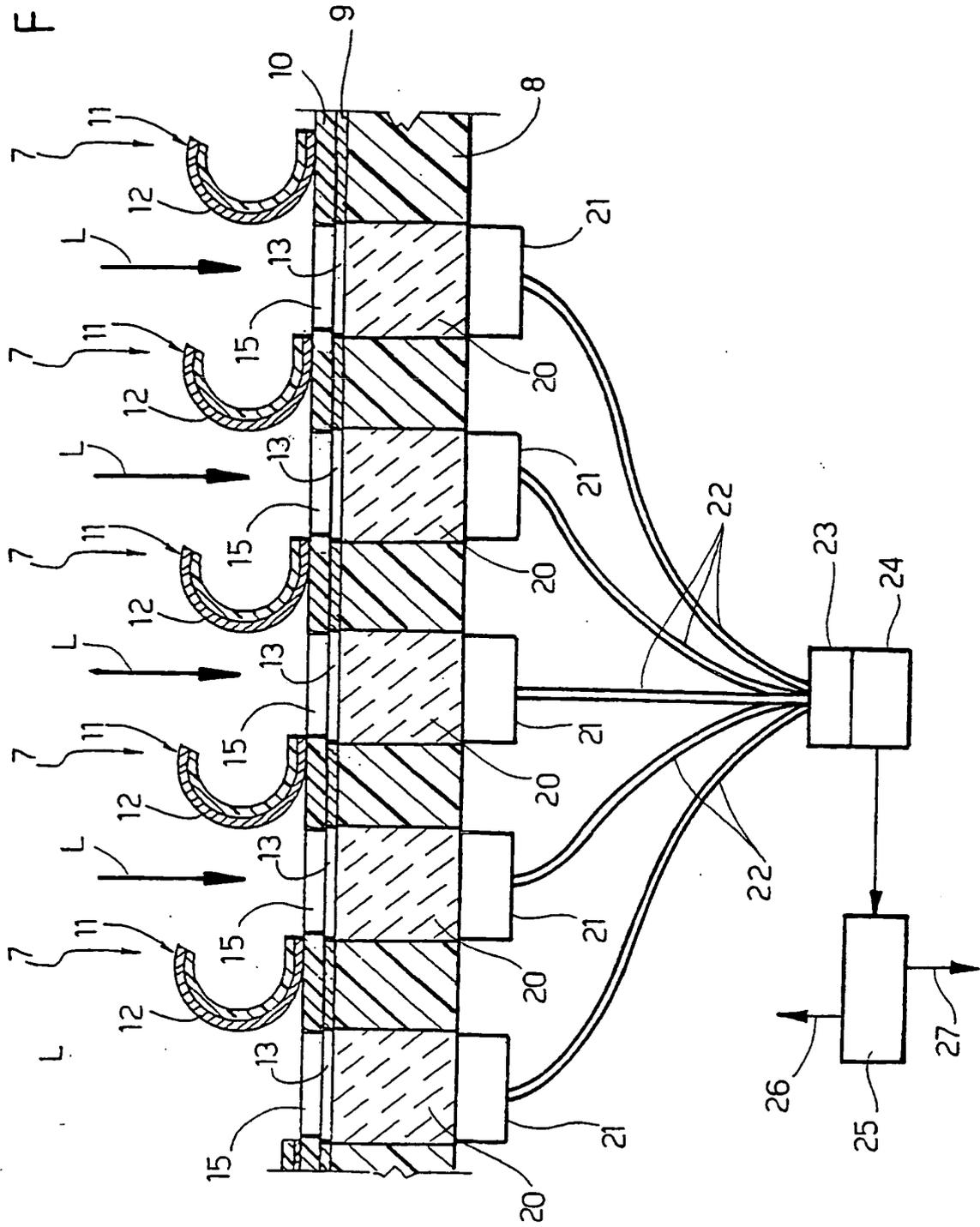


FIG. 5

